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Additive Manufacturing Applications: from Personal Protective Equipment to Sustainable High-Performance Construction Systems

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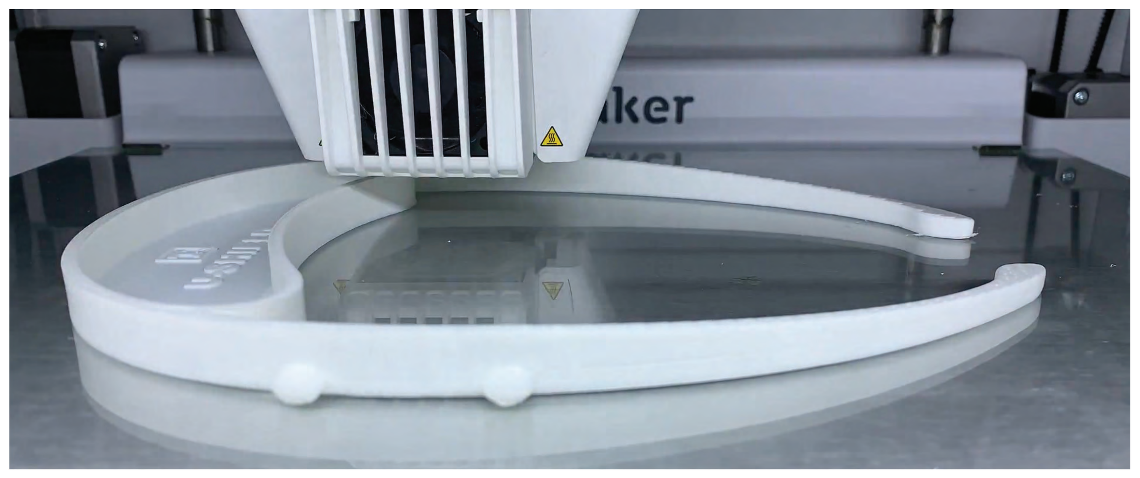
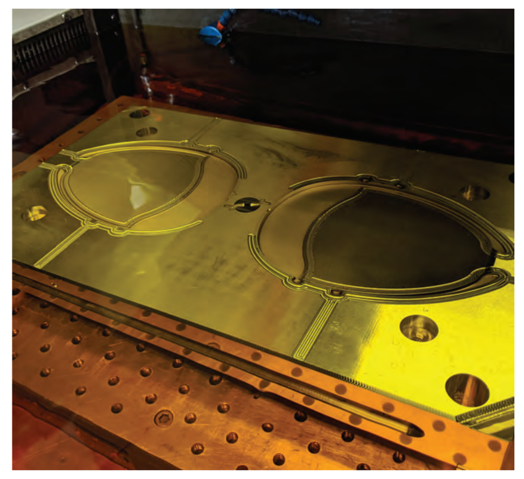
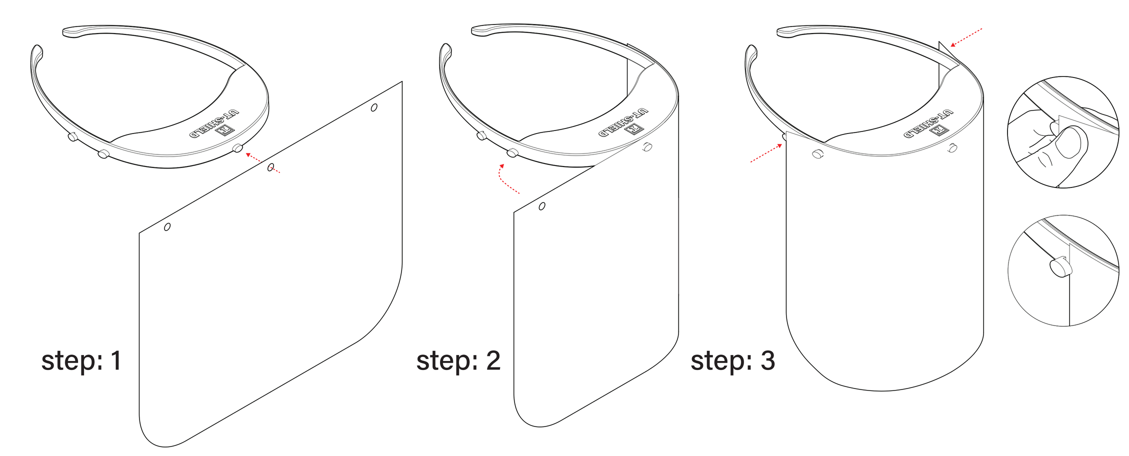
ADDITIVE MANUFACTURING APPLICATIONS: FROM PERSONAL PREOTECTIVE EQUIPMENT TO SUSTAINABLE HIGH-PERFORMANCE CONSTRUCTION SYSTEMS

UT FACE SHIELD FOR COVID-19


UT Face Shield 3D print


UT Face Shield injection mold


Use in the medical field



Instrucitonal steps for quick assembly

With the introduction of COVID-19 to the world, new precautions and changes to day-to-day life have become necessary. As a response to mitigate some of these changes, many people in the 3D printing community have developed face shields for cheap mass production in order to aid medical workers on the front lines. Aware of the changes that COVID-19 would make to my original research schedule, I refocused part of my summer efforts to help in the development of UT's own face shield while maintaining my experimentation with additive manufacturing. The driving purpose for the UT face shield design is maximizing comfort while still providing maximum protection. This is done by integrating three main design ideas - one size fits all, as lightweight as possible, and quick assembly. Some of these ideas were achieved through the capabilities of 3D printing, while others were intentional, like the format of the clear shields pegs/holes to match a standard 3-hole punch.

While designing the UT face shield, several doctors and nurses were asked to test the design in order ensure comfort. This helped to garauntee certain aspects worked correctly, like the face shield's compatibility with glasses, and to make sure that one size did fit all.

The finished 3D printed design for the UT face shield was submitted for the 3D Pioneers Challenge in Germany and was a finalist in the competition among many other designs for additive manufacturing, several of which also addressed the COVID-19 pandemic.

Following the development of the UT face shield for 3D printing, the 3D Pioneers Challenge, and obtaining a pending patent, plans to modify and prepare the design for mass production through injection molding arose. By taking advantage of the University of Tennessee's resources, a finished mold was able to be manufactured and now, while still maintaining key features like quick assembly and protection, the face shield could be produced at a cheaper and faster rate.

With the injection mold process, 50,000 face shields have been produced for the UT campuses and will be provided for faculty, staff, and students.

Finished injection mold result

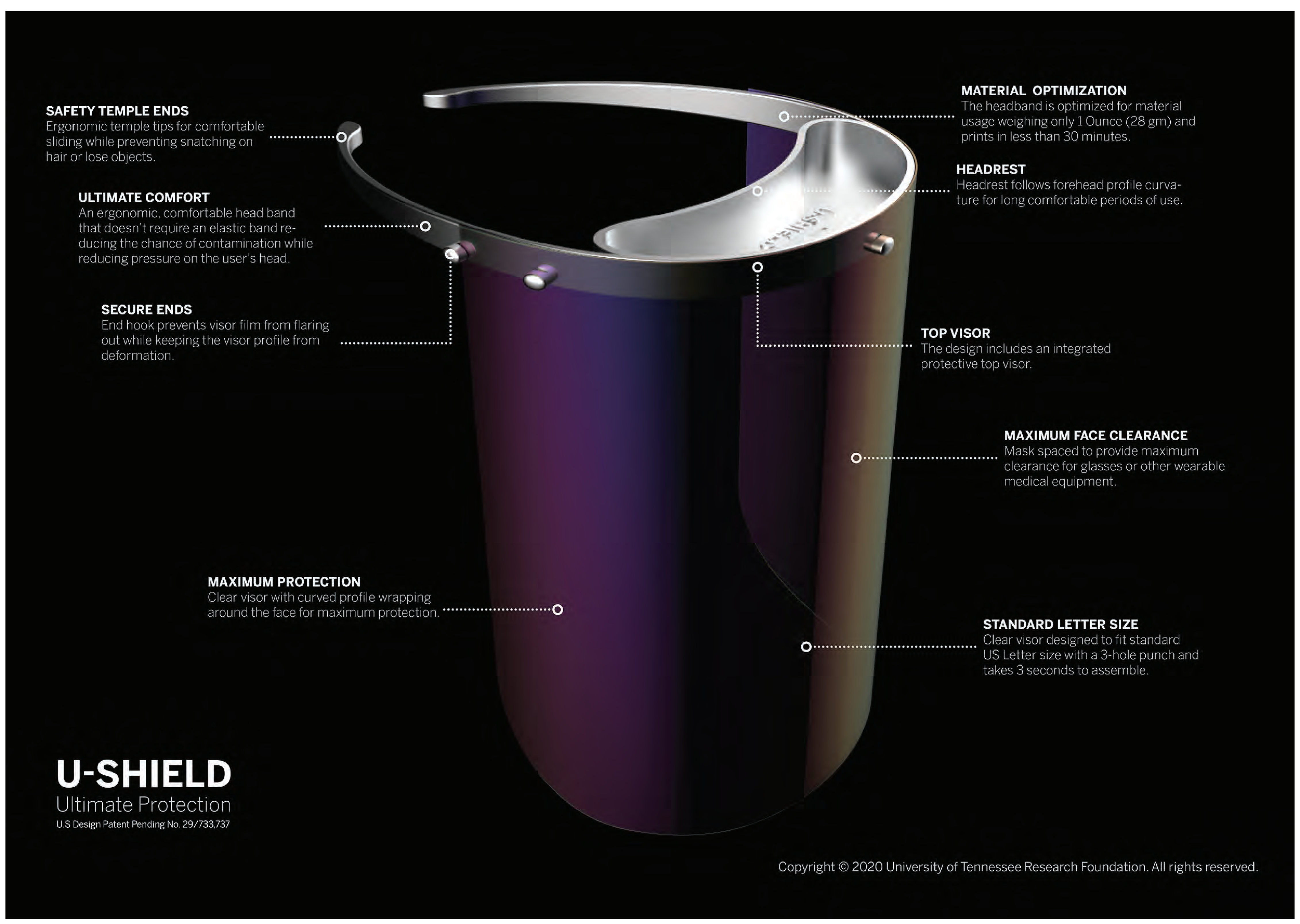
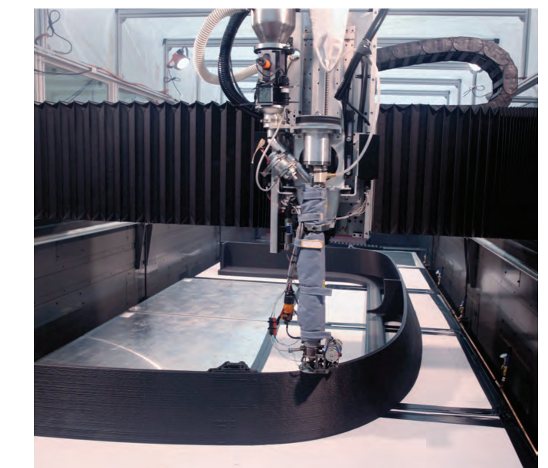


Diagram of UT Face Shield design features

ROBOTICALLY FABRICATED PERFORMANCE PANELS


Timber frame construction in 1877

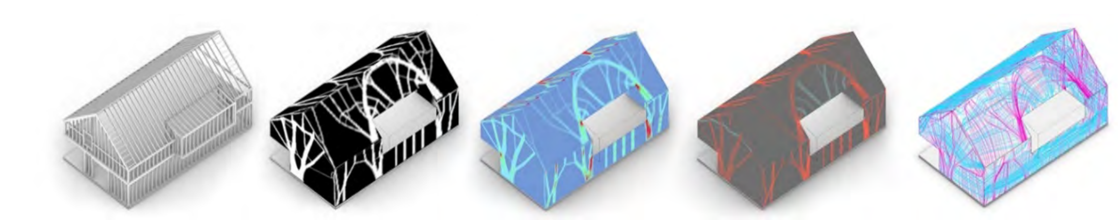

Modern framing construction

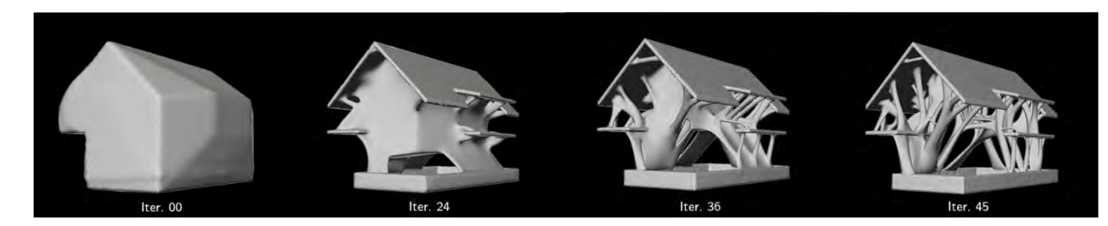

Oak Ridge large scale 3D printing for AMIE 1.0


Assembly detail from AMIE 1.0

Problem Statement:
Current conventional construction methods contribute to a significant amount of the total waste in the U.S. which has a major negative financial and environmental impact on the American economy. According to the Environmental Protection Agency (EPA), conventional construction methods generated up to 547,000 tons of waste in the United States in 2015 with 61% from non-residential and 39% from residential construction. Evidently, there is a global demand to investigate entirely new design workflow approaches and construction processes.

Preliminary Data:
The majority of the conventional construction methods are considered "subtractive", as they require removal of material through trimming, milling and drilling in order to produce final useable parts. In contrast, Additive Manufacturing (AM), or 3d-printing, is based on an additive, layer-by-layer, waste-free process allowing the generation of complex geometries directly from a digital model. Small scale construction projects, like AMIE 1.0, supported by the UT Governor's Chair, Skidmore Owings & Merrill (SOM) and Oak Ridge, have shown the potential for AM in construction. Nevertheless, AM has been limited to these small scale porotypes and has not yet been implemented into large scale building construction practices.


Model house comparing timber framing & 2D topology optimization (fig. 1)



Results of model treated as one volume (3D topology optimization) (fig. 2)

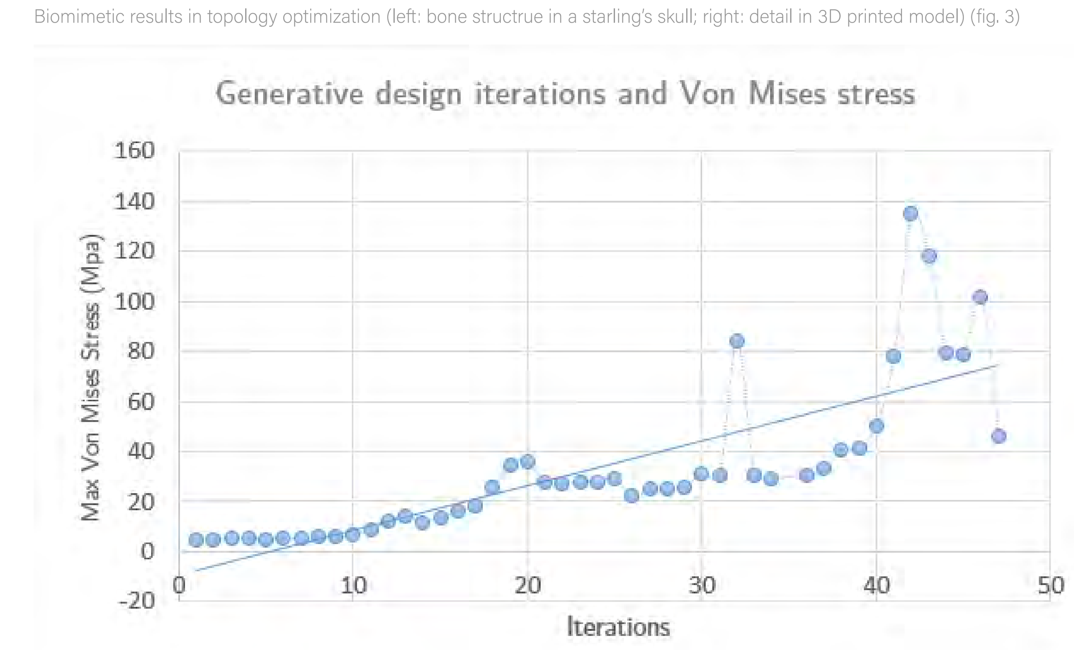
Overview:
One of the most important tasks in the integration of AM to modern construction is developing a workflow that accounts for load-bearing structure, integrated mechanical, eletrical, and plumbing (MEP) systems, and of all things, assembly. In order to achieve the aformented requirements, the AM workflow will be centered around a specific key step, topology optimization. In topology optimization, load and suppport values and locations are used to calculate stresses in the model that result in a unique optimized form.

Above (fig. 1), several calculations can be seen that present a new structural system compared to that of the typical timber frame construction. Another important aspect in the worklow not previously mentioned is time. 2D topology optimization is typically more efficient than 3D, however these results leave additional steps to be developed as assembly of this structure cannot be easily 3D printed.

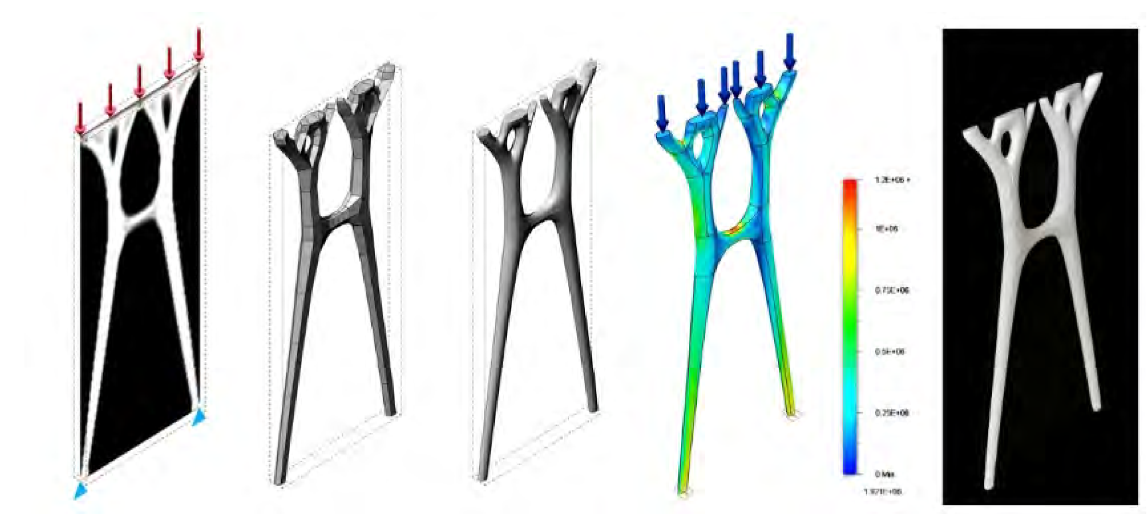
To the right (fig. 2), a full 3D topology optimization of the same model was performed, presenting yet another unique structural system. In the figure below (fig. 3), a comparison of a starlings skull and a detailed view of the 3D printed result reveal some previously unexpected biomimetic properties of the topology optimization. Additionally, a graph of the Von Mises stresses (fig. 4) on the model can be seen for each iteration in the optimization where overtime the average stress appears to increase. Similar to the 2D optimization, however, the 3D optimization leaves additional steps to be developed as the new structure interferes with previously usable space.

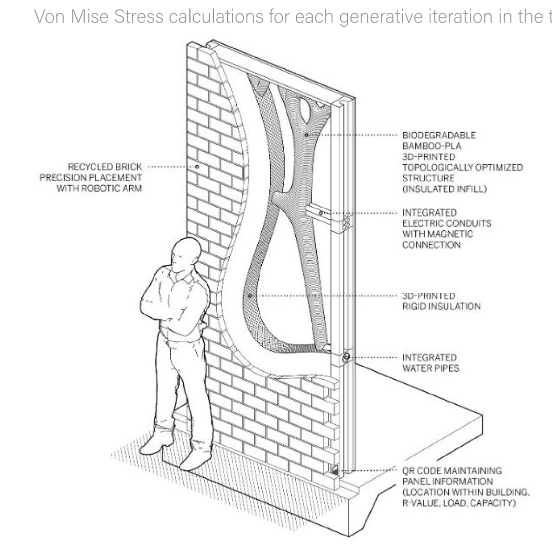
In order to minimize additional steps through the optimization of an entire model, a 1.25m x 3m wall panel will be used as a proof of concept scale for topology optimization. This is also appropriate as AM somewhat lends itself to prefabrication construction. Preliminary tests in topology optimization of this wall panel resulted in an form typical of rectalinear topology optimization. Nevertheless, what was important was the workflow from original from, to 3D print. For this, a quick 2D optimization was run, then a low polygon mesh was developed, then refined, and a finite stress analysis performed.


Biomimetic results in topology optimization (left: bone structrue in a starling's skull; right: detail in 3D printed model) (fig. 3)



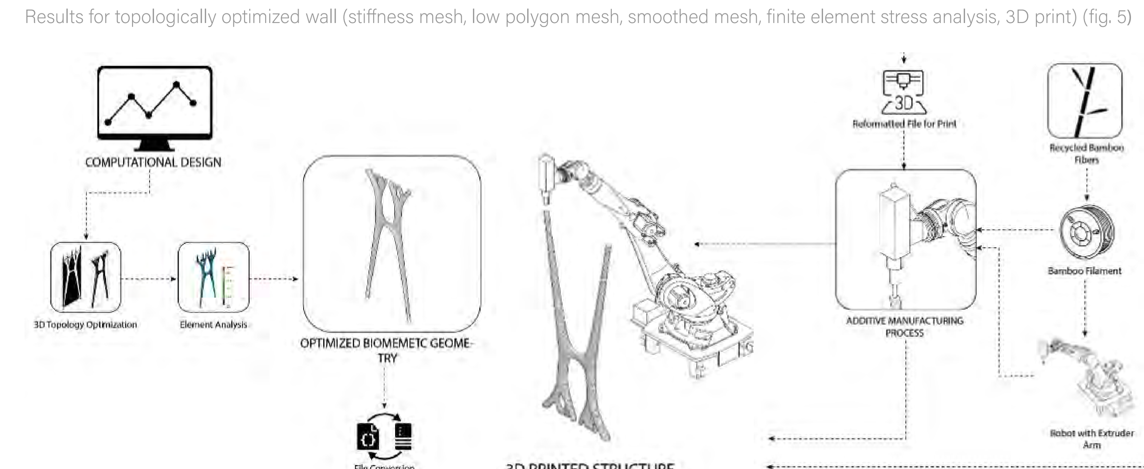
Von Mise Stress calculations for each generative iteration in the topology optimization algorithm (fig. 4)


Results for topologically optimized wall (stiffness mesh, low polygon mesh, smoothed mesh, finite element stress analysis, 3D print) (fig. 5)

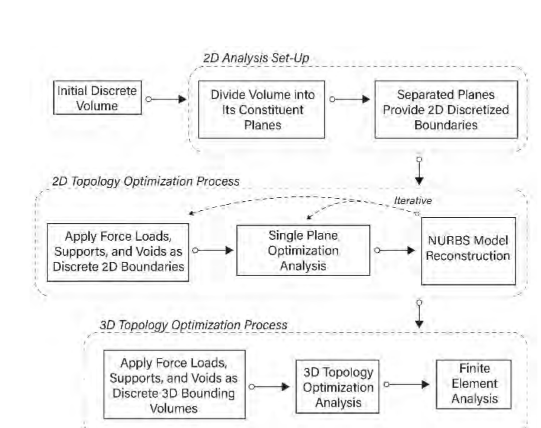

Concept sketch of a wall panel utilizing optimized structure (fig. 6)

Conclusion:
As previously outlined, though, the topologically optimized form is the focus of the AM workflow with several other steps being built around it. Mechanical, electrical, and plumbing systems still need to be integrated as well as solutions for insulation, interior and exterior cladding, and assembly with other wall panels. The diagram to the left (fig. 6) shows a concept of what this finalized panel may resemble. With the structure being 3D printed, systems that require conduit like electrical could be easily implemented while insulation has several options, one possibility being 3D printing the insulation in addition to the structure.

Further workflows including multiple softwares for both topology optimization and additional systems are still being developed, and with the rapid advancments in additive manufacturing and computer aided design, the future looks promising.



Workflow diagram for large scale robotic 3D printing of the optimized structure (fig. 7)



Workflow diagram for finding an optimized topology (fig. 8)

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Design Patents:
29/733,737, COVID-19 3d-Printed Egeronomic Face Sheild
29/739,749, COVID-19 Injection Molded Egeronomic Face Sheild